ME 327: Design and Control of Haptic Systems
Spring 2020

Lecture 15: Teleoperation: Implementation

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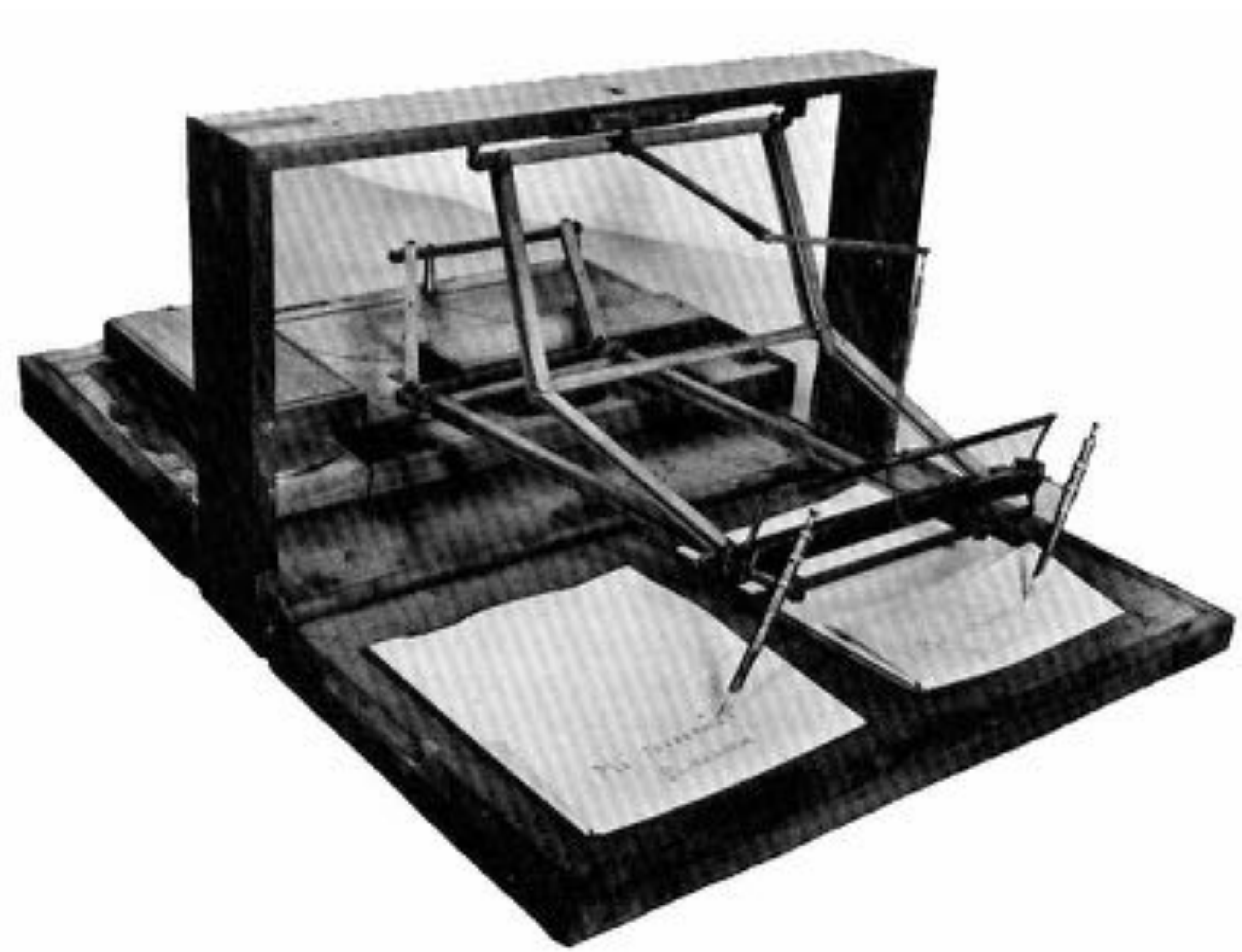
teleoperation history and examples

the genesis of teleoperation?



a Polygraph is a mechanical device that produces a copy of a piece of writing simultaneously with the creation of the original, using pens and ink. Famously used by Thomas Jefferson ~1805.

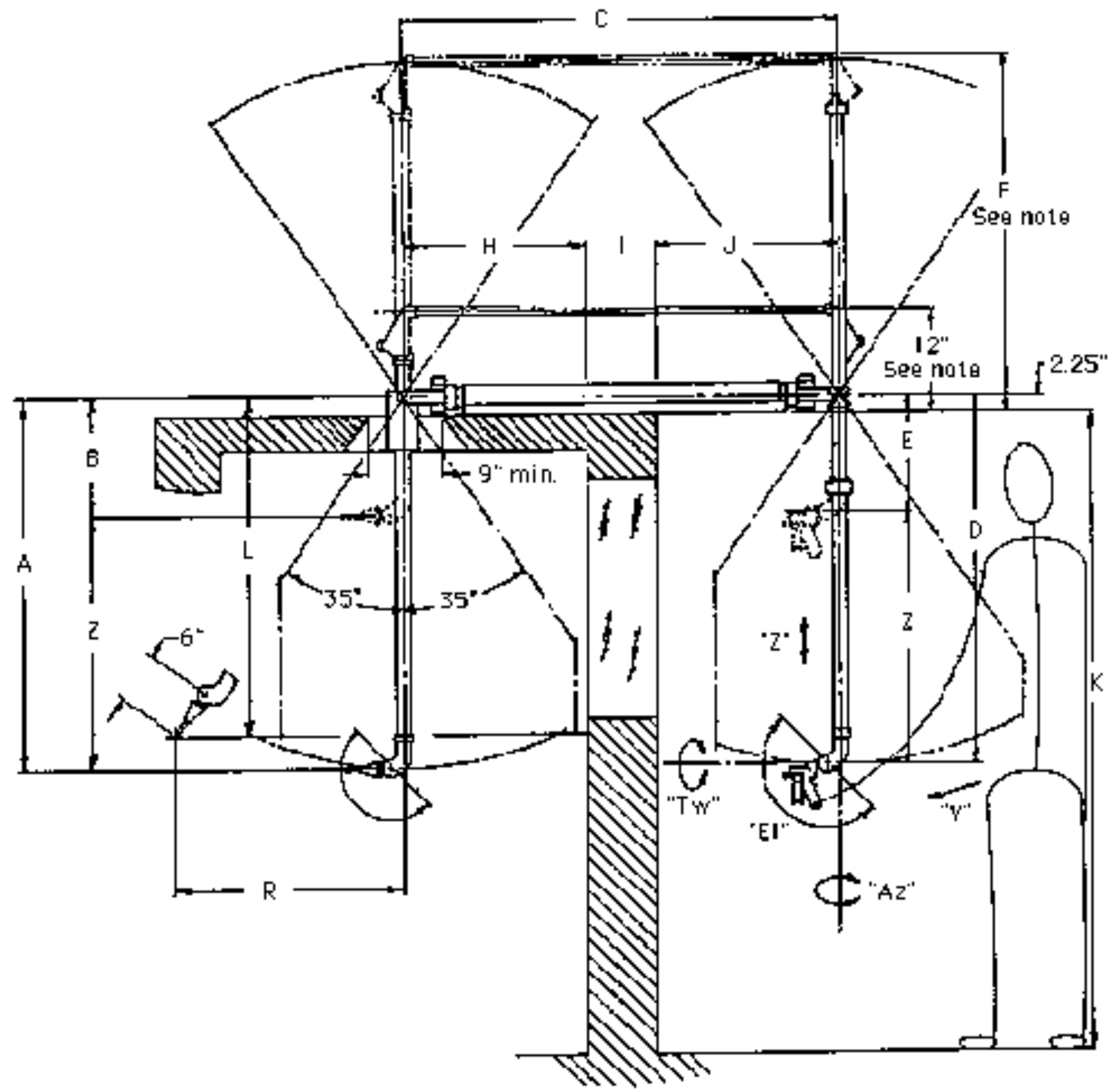
Typically uses a pantograph mechanism: a five-bar linkage with parallel bars such that motion at one point is reproduced at another point

teleoperation history

- first telemanipulator: 1948, Ray Goertz, U.S. Atomic Energy Commission
  - goal was to protect workers from radiation, while enabling precise manipulation of materials
  - a device which is responsive to another device is called the "follower" and the controlling device is termed a "master"
- at first, mechanical linkages and cables
- 1954: electrical and hydraulic servomechanisms
- 1960s: closed-circuit television and head-mounted displays (HMDs)

bilateral control = force feedback

- inherent in "mechanical" teleoperators
- forces at the follower end-effector are reflected to the master end-effector
- displacements produced at the follower end-effector produce a displacement at the master end-effector



modern telemanipulators

- undersea: exploration and oil acquisition
- space
  - 1967: Surveyor III landed on the surface of the Moon (a few seconds delay in the two-way transmission to earth of commands and information)
  - 1976: Viking spacecraft, landed on Mars was programmed to carry out strictly automated operations
  - Shuttle Remote Manipulator System (SRMS): retrieves satellites and place them in the cargo bay; mobile work platform for astronauts during space walks

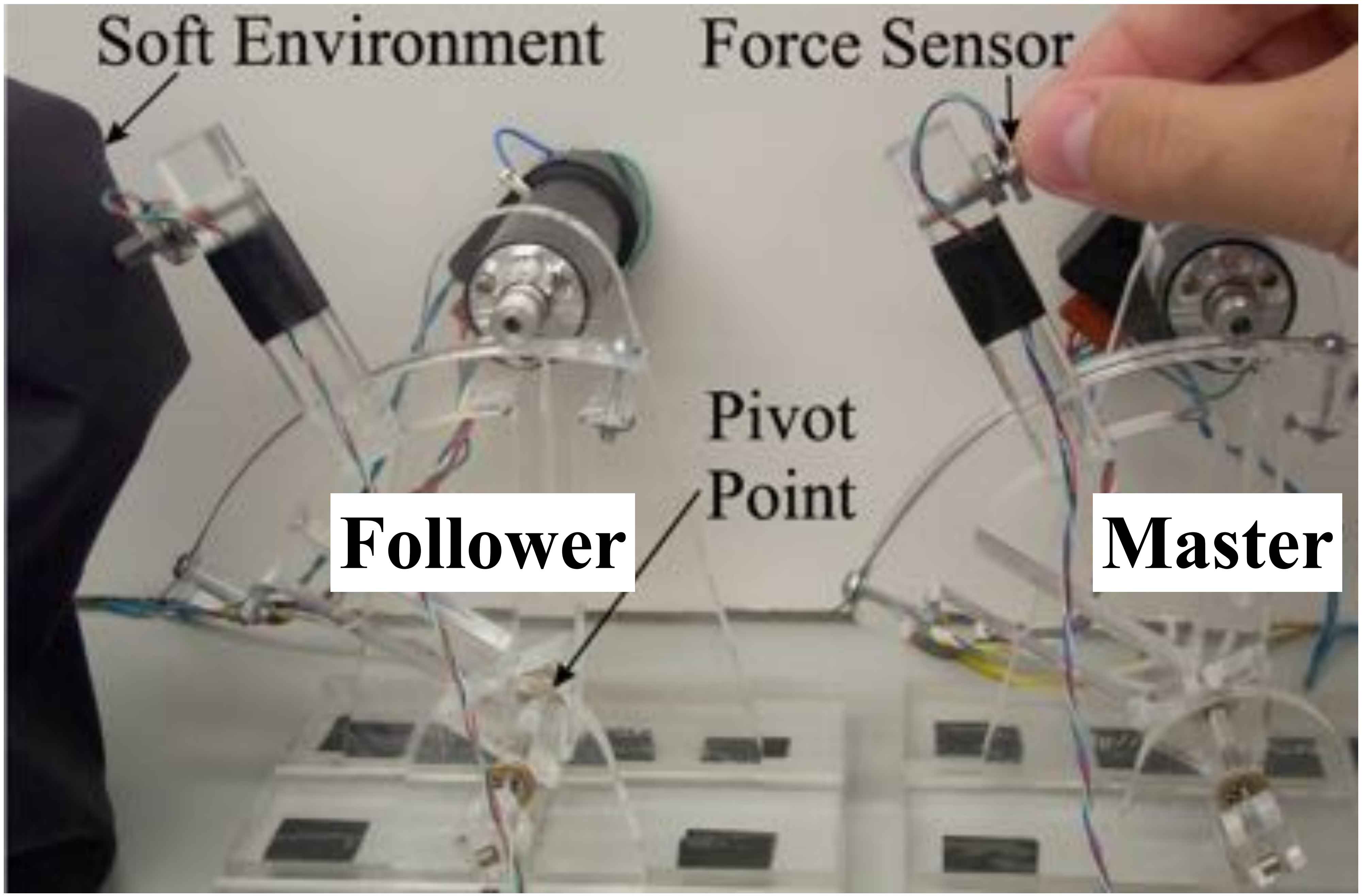
even more dexterous teleoperation

- Robonaut
  - Robot Systems Technology Branch at NASA's Johnson Space Center
  - purpose is to replace astronauts in dangerous missions, such as space walk, on the space shuttle and/or the space station
  - both autonomous operation and teleoperation are being developed

surgical robotics

(e.g., da Vinci Surgical System)

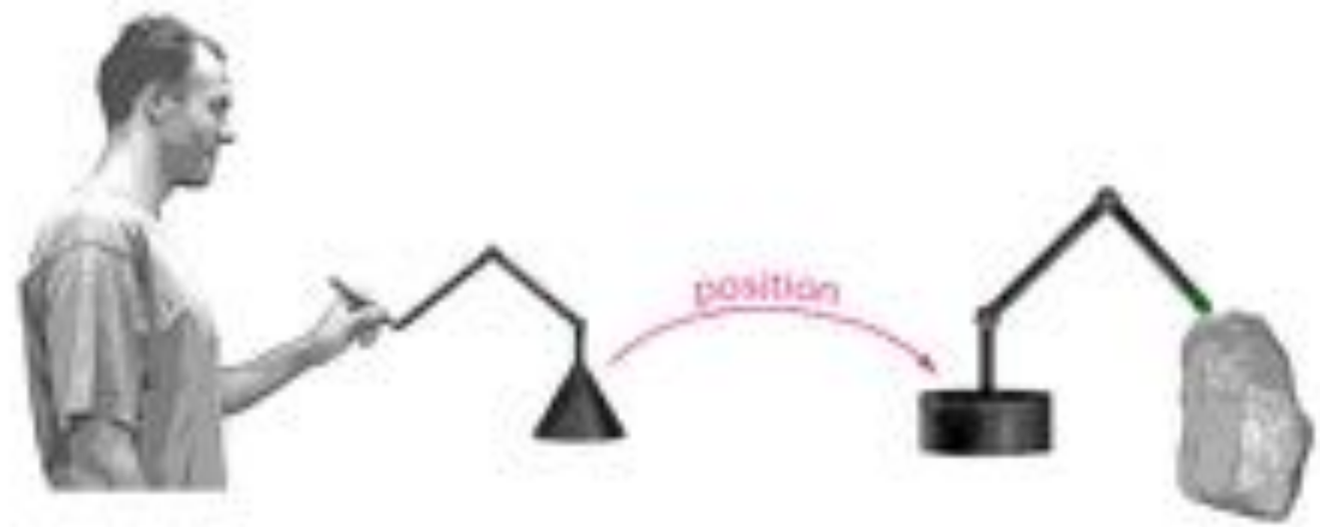
simple system example

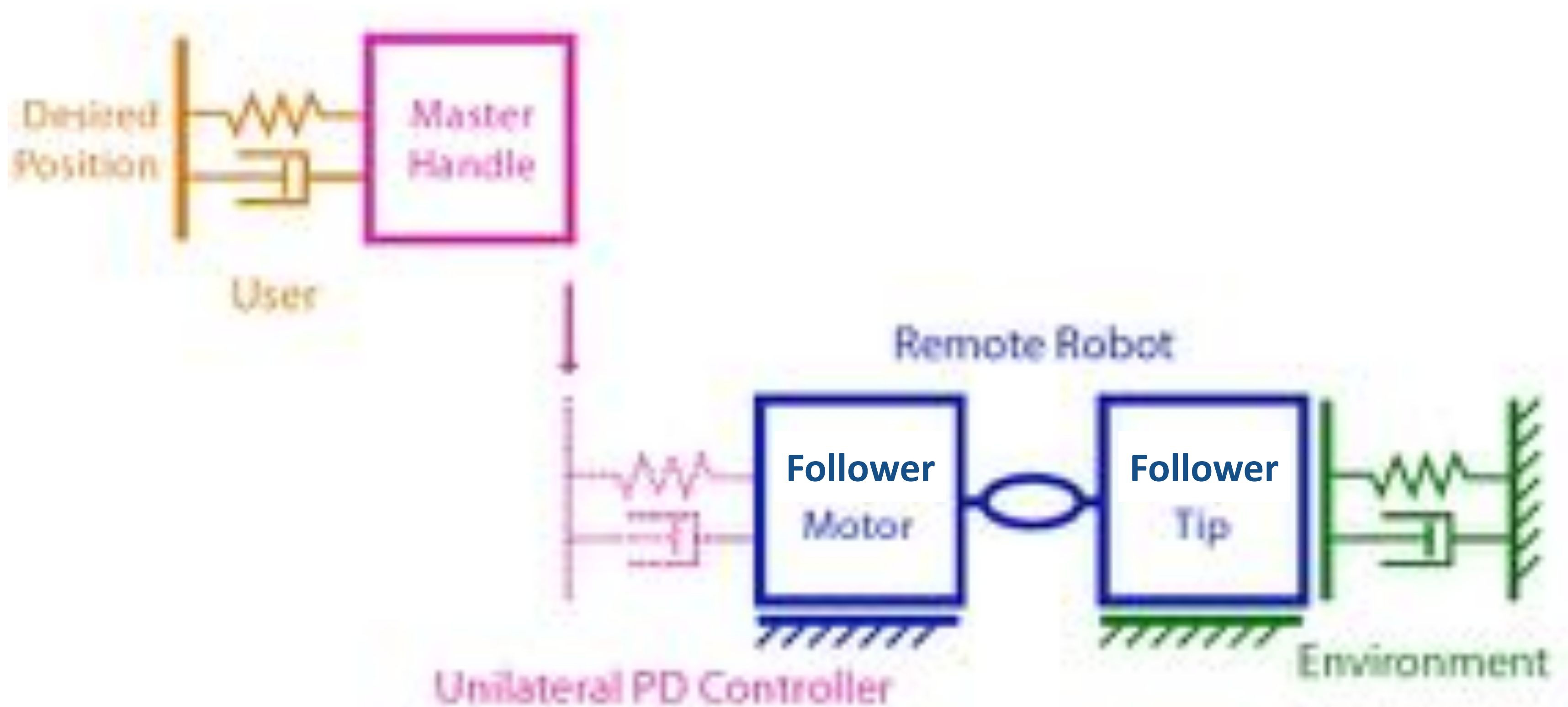


Abbott and Okamura 2004

teleoperation controllers

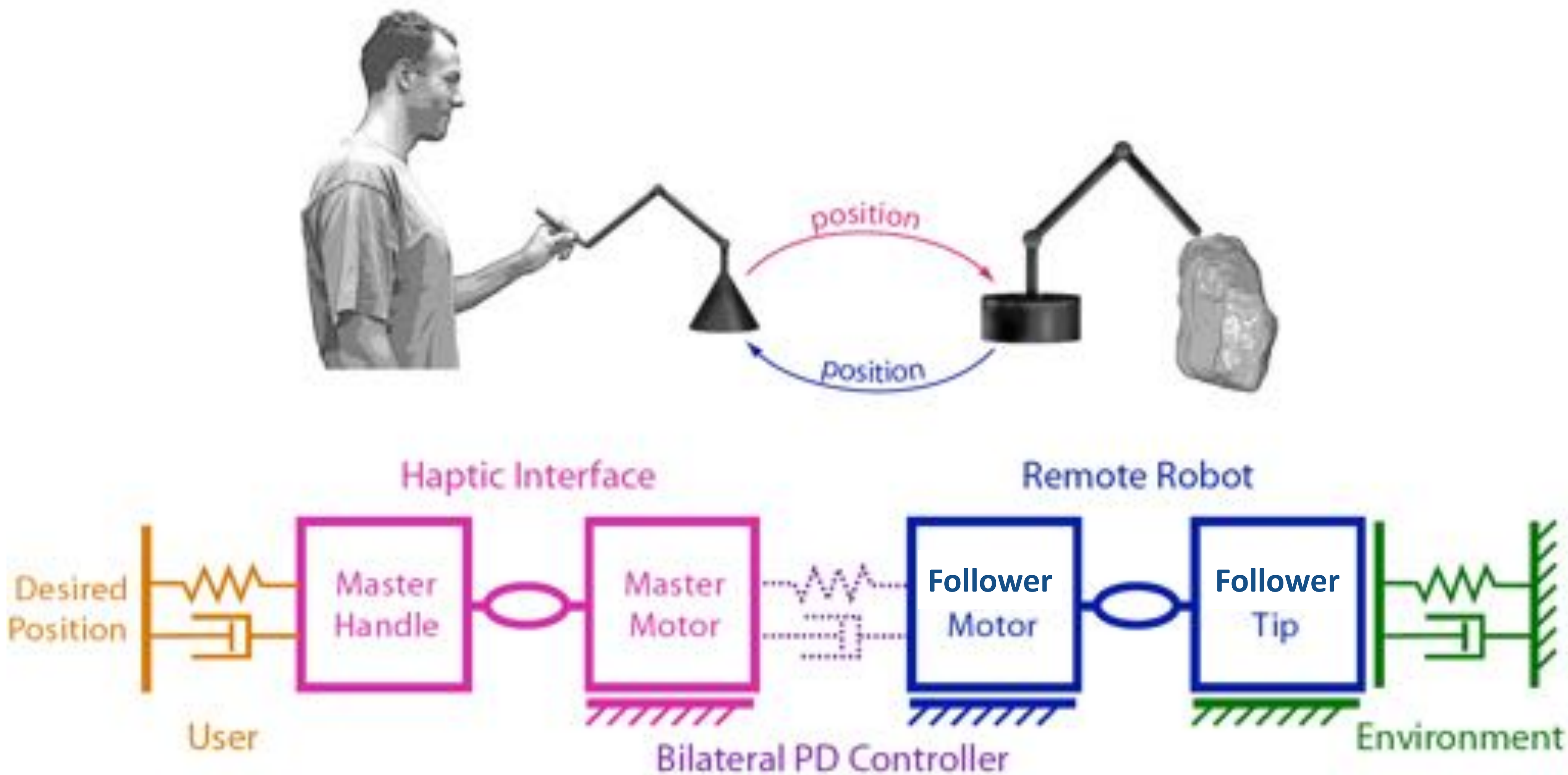
unilateral teleoperator model





modified from Kuchenbecker Ph.D. Thesis (2006)

bilateral teleoperator model (using position)



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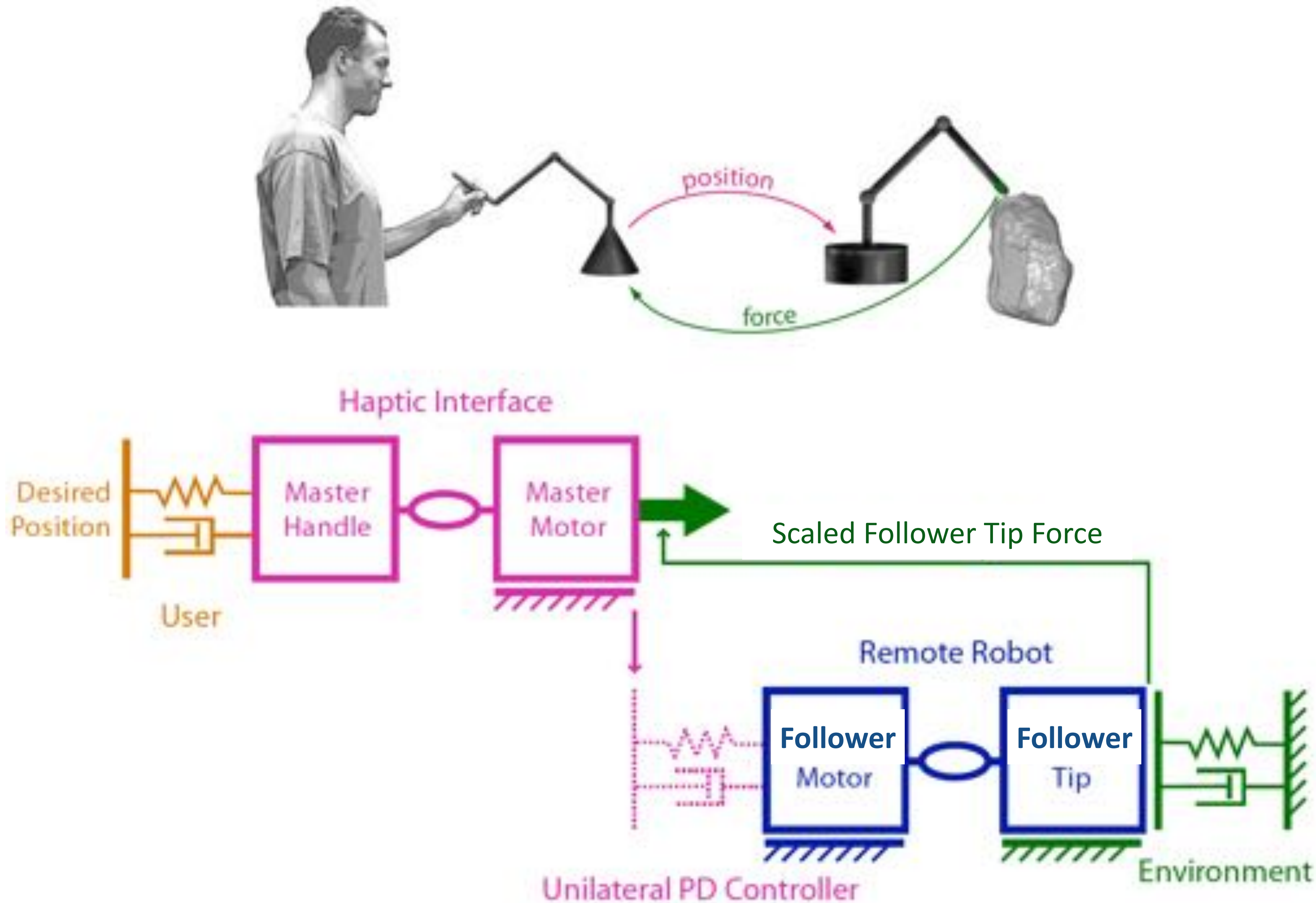
bilateral teleoperator model (using force)



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teleoperation block diagrams

typical follower robot controller

this is a proportional-derivative controller, which attempts to make the follower (2) follow the master (1) position *and* velocity

$$f_{a2}(t) = k_{p2}(x_1 - x_2) + k_{d2}(\dot{x}_1 - \dot{x}_2)$$

$f_{a2}(t)$ follower actuator force

x_1 position of master

x_2 position of follower

k_{p2} follower proportional gain

k_{d2} follower derivative gain

for each "haptic loop" the master's position is recorded and the follower robot attempts to follow the master

master robot controller for unilateral teleoperation

$$f_{a1}(t) = 0$$

$f_{a1}(t)$ master actuator force

the force applied by the master actuator (if it exists) is zero

master robot controller for bilateral teleoperation (using position)

$$f_{a1}(t) = k_{p1}(x_2 - x_1) + k_{d1}(\dot{x}_2 - \dot{x}_1)$$

$f_{a1}(t)$ master actuator force

x_1 position of master

x_2 position of follower

k_{p1} master proportional gain

k_{d1} master derivative gain

for each "haptic loop," the follower's motion is recorded and the master robot attempts to follow the follower

master robot controller for bilateral teleoperation (using force)

$$f_{a1}(t) = f_e$$

$f_{a1}(t)$ master actuator force

f_e measured environment force

for each "haptic loop," the force between the follower and the environment is measured, and the master robot outputs this amount of force

implementation summary

follower robot controller

$$f_{a2}(t) = k_{p2}(x_1 - x_2) + k_{d2}(\dot{x}_1 - \dot{x}_2)$$

master robot controller

unilateral teleoperation:

$$f_{a1}(t) = 0$$

bilateral teleoperation (position-exchange):

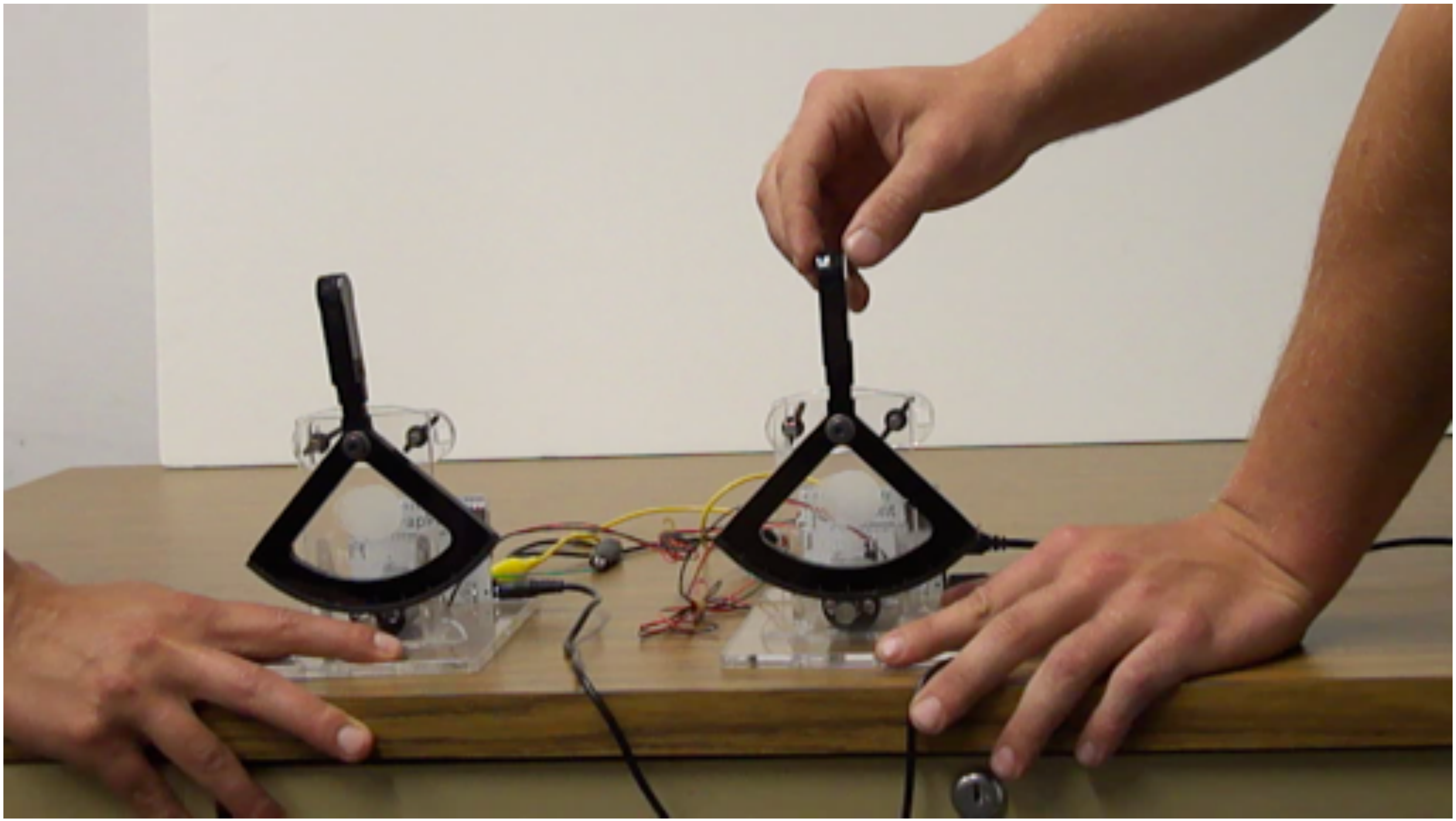
$$f_{a1}(t) = k_{p1}(x_2 - x_1) + k_{d1}(\dot{x}_2 - \dot{x}_1)$$

bilateral teleoperation (position forward, force feedback):

$$f_{a1}(t) = f_e$$

Teleoperation Setup with Hapkits

hapkit example



implementation summary

follower robot controller

$$f_{a2}(t) = k_{p2}(x_1 - x_2) + k_{d2}(\dot{x}_1 - \dot{x}_2)$$

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unilateral teleoperation:

$$f_{a1}(t) = 0$$

bilateral teleoperation (position-exchange):

$$f_{a1}(t) = k_{p1}(x_2 - x_1) + k_{d1}(\dot{x}_2 - \dot{x}_1)$$

bilateral teleoperation (position forward, force feedback):

$$f_{a1}(t) = f_e$$

Suggestions

- Connect both motors to one Hapkit Board. Call the Hapkit with this board the “master”.
- Connect the MR sensor on the “follower” Hapkit Board to an analog input on the “master”.
- Duplicate all functions in code to include “follower” Hapkit (sections previously do not edit)
- The “follower” MR sensor still needs power!
- Add a common ground between Hapkits!
- Duplicate all functions in code to include “follower” Hapkit.

Hapkit Board Pin Mapping (version 11.14.2013)

ATmega 328 chip pin #	ATmega 328 pin name	Typical Arduino function	Special Hapkit function	Pin name printed on Hapkit Board	Pin number to use in Arduino program
1	PC6 (PCINT14/Reset)	Reset	Reset	RST	
2	PD0 (PCINT16/RXD)	Digital Pin 0 (RX)		D0	0
3	PD1 (PCINT17/TXD)	Digital Pin 1 (TX)		D1	1
4	PD2 (PCINT18/INT0)	Digital Pin 2		D2	2
5	PD3 (PCINT19/OC2B/INT1)	Digital Pin 3 (PWM)		D3	3
6	PD4 (PCINT20/XCK/T0)	Digital Pin 4	SD card Slave Select Line	D4	4
7	VCC	VCC			
8	GND	GND		GND	
9	PB6 (PCINT6/XTAL1/TOSC1)	Crystal			
10	PB7 (PCINT7/XTAL2/TOSC2)	Crystal			
11	PD5 (PCINT21/OC0B/T1)	Digital Pin 5 (PWM)	PWM Output for Motor 1	D5	5
12	PD6 (PCINT22/OC0A/AIN0	Digital Pin 6 (PWM)	PWM Output for Motor 2	D6	6
13	PD7 (PCINT23/AIN1)	Digital Pin 7	Direction Output for Motor 2	D7	7
14	PB0 (PCINT0/CLKO/ICP1)	Digital Pin 8	Direction Output for Motor 1	D8	8
15	PB1 (OC1A/PCINT1)	Digital Pin 9 (PWM)	Grove Connector Output	D9	9
16	PB2 (SS/OC1B/PCINT2)	Digital Pin 10 (PWM)	Grove Connector Output	D10	10
17	PB3 (MOSI/OC2A/PCINT3)	Digital Pin 11 (PWM)	Data In for SD Card	D11	11
18	PB4 (MISO/PCINT4)	Digital Pin 12	Data Out for SD Card	D12	12
19	PB5 (SCK/PCINT5)	Digital Pin 13	Serial Clock Line for SD Card	D13	13
20	AVCC	VCC			
21	AREF	Analog Reference		AREF	
22	GND	GND		GND	
23	PC0 (ADC0/PCINT8)	Analog Input 0	Grove Connector Output	A0	A0
24	PC1 (ADC1/PCINT9)	Analog Input 1	Grove Connector Output	A1	A1
25	PC2 (ADC2/PCINT10)	Analog Input 2	MR Sensor Output	A2	A2
26	PC3 (ADC3/PCINT11)	Analog Input 3	FSR Output	A3	A3
27	PC4 (ADC4/SDA/PCINT12)	Analog Input 4		A4	A4
28	PC5 (ADC5/SCL/PCINT13)	Analog Input 5		A5	A5